Coastal Engineering Technical Note

THE COASTAL MODELING SYSTEM: A SYSTEM OF NUMERICAL MODELS AND SUPPORT PROGRAMS

PURPOSE: As part of its research mission, the Coastal Engineering Research Center (CERC) has developed a number of numerical models for studying a variety of coastal processes, including storm surge, tidal and wind-driven circulation, and wave generation and transformation. It is CERC's goal to transfer this technology to Corps elements through computer-based systems. For those models that are computationally- and memory-intensive, this transfer will be made via the *Coastal Modeling System* (CMS), (Cialone et. al. 1991, 1992, 1993). The CMS is a software package aimed at organizing CERC's larger numerical models and their supporting software into a well-documented, user-friendly system that is available to all Corps elements having a need to apply the supported modeling technology.

Several objectives are followed in developing and expanding CMS. Since some of the models share similar input requirements, output capabilities, and procedural implementation, efforts are made to standardize these portions of the models as much as possible. This standardization promotes efficiency because coding effort is reduced, new users learn the models in the system more rapidly, and chances for errors in entering input or interpreting output are reduced because of user familiarity with the system structure.

COMPONENTS: The CMS is a supercomputer-based system of models and supporting software packages. Presently, this system contains twelve models, which are:

a) the *WES Implicit Flooding Model* (WIFM) for simulating shallow-water, long-wave hydrodynamics;

b) the *Standard Project Hurricane* (SPH) model for computing wind velocities and atmospheric pressure fields generated by hurricanes;

c) the *Regional Coastal Processes WAVE propagation* (RCPWAVE) model for determining short-wave transformation in open coast regions;

d) the *Curvilinear Long-wave HYDrodynamic* (CLHYD) model for simulating shallow-water, long-wave hydrodynamics using a boundary-fitted (curvilinear) grid system;

e) the *SHALlow-water WaVe* (SHALWV) model for simulating time dependent, irregular, shallow-water wave growth, propagation and decay;

f) the *STeady WAVE* (STWAVE) model for simulating time-independent, irregular wave propagation;

g) the *Harbor Wave Oscillation* (HARBD) model for predicting wave oscillations in harbors;

h) the GENEralized model for SImulating Shoreline change (GENESIS) for predicting long-term shoreline response;

i) the Storm-Induced BEAch CHange model (SBEACH) for simulating cross-shore profile response to storms;

j) the Planetary Boundary Layer WIND model (PBLWIND) for predicting winds near the water surface during an extratropical storm;

k) the HURricane WINd model (HURWIN) for predicting surface stress and winds in the planetary boundary layer during a tropical storm; and

l) the Wave Induced Current Model (WICM) for computing wave-induced current and water surface setup.

Model WIFM is a two-dimensional, time-dependent, long-wave model for solving the vertically integrated Navier-Stokes equations in a stretched Cartesian coordinate system. The model simulates shallow-water, long-wave hydrodynamics such as tidal circulation, storm surges, and tsunami propagation. WIFM contains many useful features for studying these phenomena such as moving boundaries to simulate flooding/drying of low-lying areas and subgrid flow boundaries to simulate small barrier islands, jetties, dunes, or other structural features. Model output includes vertically integrated water velocities and water surface elevations.

Model SPH is a two-dimensional, parametric model developed in a stretched cartesian coordinate system for representing wind and atmospheric pressure fields generated by hurricanes. It is based on the Standard Project Hurricane criteria developed by the National Oceanic and Atmospheric Administration (NOAA), and the model's primary outputs are resulting wind velocity and atmospheric pressure fields which can be used in storm surge modeling. The SPH model can be run independently, or it can be invoked from within model WIFM.

Model RCPWAVE is a two-dimensional, steady-state, short-wave model for solving wave propagation problems over arbitrary bathymetry. The governing equations solved in the model are the "mild slope" equation for linear, monochromatic waves, and the equation specifying irrotationality of the wave phase function gradient. These equations account for shoaling, refraction, and bottom-induced diffraction within a study area. The model also includes an algorithm for treating wave breaking. Model output includes wave height, wave angle, and wave number.

Model CLHYD simulates shallow-water, long-wave hydrodynamics such as tidal circulation and storm surge propagation. CLHYD can simulate flow fields induced by wind fields, river inflows/outflows, and tidal forcing. CLHYD is similar to WIFM, with the added feature of operating on a boundary-fitted (curvilinear) grid system. However, CLHYD cannot simulate flooding/drying of low-lying areas as WIFM can. Model output includes vertically integrated water velocities and water surface elevations.

Model SHALWV is a two-dimensional, pseudo-discrete, time-dependent spectral wave model for simulating wave growth, decay, and transformation. Developed in a rectangular cartesian coordinate system, the model is based on the solution of the inhomogeneous energy balance equation via finite difference methods. This equation accounts for several mechanisms, including wind-wave growth, refraction, shoaling, nonlinear wave-wave interactions, high-frequency energy dissipation, surf zone breaking, and decomposition of energy into wind-sea and swell wave components. Model output includes one-dimensional frequency and two-dimensional frequency-direction spectra.

Model STWAVE is a computationally efficient finite-difference model for nearcoast time-independent spectral wave energy propagation simulations. The efficiency of the program is due to the assumption that only wave energy directed into the computational grid is significant, i.e., wave energy not directed into the grid is neglected. The program also assumes that wave conditions vary sufficiently slowly such that the variation of waves at a given point over time may be neglected relative to the time required for waves to pass across the computational grid. While these assumptions minimize computations, they also limit the model to nearcoast applications in which waves are generally directed into the grid and move quickly across it (within 30 minutes). Model output includes the energy-based significant wave height, peak spectral period, and mean spectral direction for each point on the computational grid. In addition, the frequency and frequency-direction wave energy spectra at user-specified grid locations along with the energy-based wave height, peak spectral period, and mean spectral propagation direction for the total energy spectrum at these same user-specified locations are output by the model.

Model HARBD is a two-dimensional, steady-state, finite-element model for studying wave oscillations in and around harbors, and is applicable to harbors having arbitrary depths and geometric configurations. This model is based on linear wave theory, and solves a boundary value problem of harbor resonance and wave scattering which include the effects of bottom friction. The model may also be applied to weakly nonlinear waves, though great care must be exercised while interpreting results. The model should not be used for certain applications (i.e., strongly nonlinear cases). The model neglects wave-wave and wave-current interaction, wave breaking, and wave transmission or overtopping of structures such as breakwaters or jetties. Model output includes wave height amplification factors and wave phases.

Model GENESIS is a one-dimensional model for simulating long-term shoreline change. It can predict shoreline change and longshore transport rates under a wide range of beach, coastal structure, wave, initial, and boundary conditions, which may vary in space and time, Input data include the initial shoreline position, measured shoreline position for calibration purposes, structure positions, depths along the nearshore reference line, and the wave height, period, and direction for every timestep. Model output includes the shoreline position and longshore transport rates at user-specified timesteps.

Model SBEACH is an empirically-based, two-dimensional model for predicting storm-induced beach erosion and post-storm recovery. Input requirements include a time series of deepwater wave height and period, a time series of water level, median beach grain size, and initial profile shape. Model output includes the beach profile at user-specified timesteps, as well as the cross-shore distribution of various process parameters (wave height and water level at maximum and user-specified intervals).

Model PBLWIND is a generalized numerical model used to predict winds near the water surface based on atmospheric pressure gradients and temperature differences between the air and water. PBLWIND is a steady-state model which includes computational modules for geostrophic, gradient, and surface boundary layer winds. The model should not be used for modeling hurricanes and tropical storms because their compact size, intense pressure gradients, and rapid changes in time require special treatment. Output from PBLWIND consists of wind speed and direction at a desired elevation above the water surface which can be used as input to a hydrodynamic model (SHALWV, WIFM, CLHYD).

Model HURWIN is a two-dimensional, time-dependent model for predicting surface stress and wind speed and direction in the planetary boundary layer of a tropical cyclone. Wind information is calculated from meteorological storm parameters available for historical hurricanes and provided at a user-specified elevation. The model is based on the momentum equations vertically-averaged through the depth of the planetary boundary layer. Options are also provided for estimating surface wind over terrain of specified roughness including lakes, marshes, plains, woods, and cities. It has been used extensively in the Wave Information Studies (WIS), (Abel, C.E., Tracy , B.A., Vincent, C.L., Jensen, R.E. 1989), to hindcast historical hurricanes along U.S. coasts.

Model WICM is a two-dimensional, depth-averaged model for computing wave-induced currents and water surface setup. WICM can simulate flow fields induced by waves, winds, river inflows/outflows, and tidal forcing. Similar to CLHYD, this finite difference model is developed in boundary fitted (curvilinear) coordinates. In addition to the forcing mechanisms in CLHYD, WICM includes wave stresses (gradients in radiation stress) caused by breaking waves to produce nearshore circulation and wave setup. To calculate radiation stress, WICM requires input wave fields from either a monochromatic (RCPWAVE) or spectral (STWAVE) wave model.

Software packages for supporting these models include:

a. Grid generation software (CMSGRID).
b. Post-processing software to display model results (CMSPOST).
c. Utility software to supplement data used by model (CMSUTIL).
d. Sample input and output files (CMSSAMP).
e. Automated Job Control Language (JCL) procedures to execute items (a) through (d)

The grid generation package (CMSGRID) presently contains software for creating stretched rectilinear computational grids used by several models in CMS. This software allows square or rectangular grid systems to be generated; but also employs sophisticated techniques to concentrate grid cells in regions of interest or where geographic features are irregular, and space grid cells wider in areas where conditions do not change rapidly.

The post-processing package (CMSPOST) includes graphics to plot model output for comparison and analysis purposes. Four basic types of plots are available: time-histories of a scalar variable or vector magnitude and direction at selected grid points; vector maps, or "snapshots," at a given instant in time; wave ray plots; and profile plots that show the spatial variation of a model variable at an instant in time. Software for producing contour plots will be released in December 1994.

The utility software package (CMSUTIL) presently contains two programs: a program to determine tidal constituents from a time history of tidal elevations, and a program to generate a time series of water elevations from tidal constituent input.

The sample file package (CMSSAMP) is used to access sample input files for each of the models in the CMS. This provides the user with the required format of input data and can also be used as a template for generating the user's own input file(s). In addition, sample files can be used to run a particular model in the CMS to help the user gain familiarity with the model.

Generally, CMS users are not required to learn the JCL of the host computer system. Most of the job control commands required to submit models and data files to the host computer for execution are accomplished by the CMS procedure files. However, users must be able to use an editor on the supercomputer or be able to transfer files from their local computing environment to the supercomputer.

SUPPORT: Services and products provided to Corps users include: training workshops, regional demonstrations, consulting services, and a CMS user's manual. Training Corps personnel on the usage of the CMS, and specific models contained within CMS, is accomplished via periodic workshops. Assisting Corps personnel with specific network communication problems, PC setting adjustments, and equipment specific printing procedures is provided via regional demonstrations. Currently, CERC provides limited consultation services to Corps personnel performing specific model applications via the Numerical Modeling Maintenance Fund. More intensive training can be provided as part of joint field applications between CERC and Corps elements. Experience at CERC indicates that applying these models requires a significant commitment of resources (e.g., time and manpower) to understand the complexities and intricacies of numerical modeling.

Individual models and major software packages are documented in separate chapters in the CMS user's manual. Each model and package residing in the CMS is documented so that new or infrequent users can readily apply a model. This manual is in an loose leaf format to permit efficient and cost-effective updates and additions. Manual contents include discussions of model capabilities, theory, and application. Example problems illustrating model capabilities are also contained in the manual.

REFERENCES:
Cialone A. M. 1991. "Coastal Modeling System User's Manual," Instruction Report, CERC-91-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

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Cialone A. M. et. al. 1993. "Coastal Modeling System User's Manual, Supplement 2 to September 1991 Manual," Instruction Report, CERC-91-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Abel, C.E., Tracy, B.A., Vincent, C.L., Jensen, R.E. 1989. "Hurricane Hindcast Methodology and Wave Statistics for Atlantic and Gulf Hurricanes from 1956-1975," WIS Report 19, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

AVAILABILITY: Most efforts involving the use of models in the CMS are both memory- and computationally-intensive, and require the use of large mainframe computers for their efficient execution. The CMS is installed, maintained, and supported on the U.S. Army Waterways Experiment Station's Cray Y-MP supercomputer.

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